SPIN EFFECTS IN DIFFRACTIVE REACTIONS

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Double spin asymmetries in the diffractive $Q\bar{Q}$ and J/Ψ leptoproduction are discussed. It is shown that the asymmetries for longitudinally polarized lepton and longitudinally or transversely polarized proton can be used to study spin dependent gluon distribution of the proton at small x.

1 Introduction

In this report, we study diffractive processes at high energies which are predominated by the Pomeron exchange. The Pomeron is a color singlet object which can be associated with the two-gluon state [1]. The cross section of inclusive hadron production is expressed in terms of ordinary parton distributions where partons have the same momenta. The diffractive reactions, which should give significant contribution to inclusive processes at small Bjorken $x \leq 0.1$, have a different nature. Really, in the diffractive hadron leptoproduction, like vector meson and $Q\bar{Q}$ production, the nonzero momentum x_P carried by the two-gluon system (Pomeron) appears and the gluon momenta cannot be equal. As a result, these processes can be expressed in terms of skewed parton distribution (SPD) in the nucleon $\mathcal{F}_\zeta(x)$ where x is a fraction of the proton momentum carried by the outgoing gluon and ζ is the difference between the gluon momenta (skewedness) [2]. Investigation of the diffractive reactions should play a key role in future study $\mathcal{F}_x(x)$ at small x. For the processes which involve the light quark production both quark and gluon SPD will contribute especially for not small x. We shall discuss here the diffractive charm quark production and J/Ψ production where the $q\bar{q}$ exchange in the t -channel is not important because the charm quark content in the proton is rather small. In these reactions the predominated contribution is determined by the two-gluon exchange (gluon SPD). Analysis of such diffractive reactions should throw light on the gluon structure of the proton at small x [3, 4].

To study spin effects in diffractive hadron production, one must know the structure of the two-gluon coupling with the proton at small x. In the leading Log approximation, the ladder gluon graphs give predominating contribution. In a QCD–inspired diquark model of the proton [5], such graphs have been analyzed in [6]. The model generates the spin-dependent ggp coupling at moderate momentum transfer. Using the results of [6], the following form of the coupling has been found

$$
\begin{aligned}
V_{pgg}^{\alpha\alpha'}(p,t,x_P,l_\perp) &= (\gamma^\alpha p^{\alpha'} + \gamma^{\alpha'} p^\alpha)B(t,x_P,l_\perp) + 4p^\alpha p^{\alpha'} A(t,x_P,l_\perp) \\
&+ \epsilon^{\alpha\beta\delta\rho} p_\delta \gamma_\rho \gamma_5 D(t,x_P,l_\perp).
\end{aligned} \tag{1}
$$

Here the functions $A - D$ have dependence on the transverse part of the gluon momentum $l_\perp$.

The structure $(\gamma^\alpha p^{\alpha'} + \gamma^{\alpha'} p^\alpha)B(t)$ in (1) is a coupling which determines the spin-non-flip contribution. The term $p_\alpha p_{\alpha'} A(r)$ leads to the transverse spin-flip in the vertex which does not vanish in the $s \to \infty$ limit. The first two terms of the vertex (1) are symmetric over the α, α' indices. They are equivalent to the isoscalar electromagnetic nucleon current with the Dirac and Pauli nucleon form factors [7]. In the model [8], the form (1) was found to be valid for the momentum transfer $|t| < $ few GeV^2 and the $A(t)$ amplitude was caused by the meson-cloud effects in the nucleon. Within this model, a quantitative description of meson-nucleon and nucleon–nucleon polarized scattering at high energies has been obtained [8]. The model predictions for polarization for the PP2PP experiment at RHIC was made in [9]. The expected errors are quite small and the information about the spin-flip part of the coupling (1) can be obtained experimentally. In a QCD–based diquark model the $A(t)$ contribution is determined by the effects of vector diquarks inside the proton [6], which are of an order of α_s. Diquarks provide an effective description of nonperturbative effects in the proton. The single spin transverse asymmetry predicted in the models [6, 8, 9] is about 10% for $|t| \sim 3\text{GeV}^2$ which is of the same order of magnitude as has been observed experimentally [10]. These model approaches are consistent with experiment and give the ratio

$$\frac{|A(t, x_P)|}{|B(t, x_P)|} \leq 0.1 \text{GeV}^{-1}. \tag{2}$$

The asymmetric structure in (1) is proportional to $D\gamma_\rho\gamma_5$ and can be associated with ΔG. It should give a visible contribution to the double spin longitudinal asymmetry A_{ll} [11]. Unfortunately, it does not appear for elastic scattering ($x_P = 0$) and the value of this structure is not well known from our model estimations.

In this report, we shall analyze spin effects caused by the structures A and B. It will be shown that such effects will be small in the A_{ll} asymmetry. This means that, most likely, they do not provide additional problems with extracting the $\Delta G \propto D\gamma_\rho\gamma_5$ term from the A_{ll} asymmetry in the hadron leptoproduction at small x. It will be shown that the double spin asymmetry for longitudinally polarized lepton and transversely polarized proton is mainly determined by the A term in (1). This asymmetry should be used to study this structure in the ggp coupling.

2 Vector meson production and skewed parton distribution

Let us study the diffractive J/Ψ production at high energies $s = (p + l_e)^2$ and fixed momentum transfer $t = r_P^2 = -\vec{\Delta}^2 = (p - p')^2$. Here l_e and p are the initial momenta of the lepton and proton, p' is the final proton momentum and r_P is a momentum carried by the Pomeron ($\vec{\Delta}$ is its transverse part). The vector meson production amplitude is described in addition to s and t by the variables

$$Q^2 = -q^2, \quad y = \frac{p \cdot q}{p \cdot l_e}, \quad x_P = \frac{q \cdot r_P}{q \cdot p}, \tag{3}$$

2   A

where Q^2 is the photon virtuality. The variables y and x_P determine the fractions of the longitudinal momenta of the lepton and proton carried by the photon and Pomeron, respectively. From the mass-shell equation for the vector–meson momentum $V^2 = (q + r_P)^2 = M_J^2$ we find that in this reaction

$$x_P \sim \frac{m_J^2 + Q^2 + |t|}{sy} \tag{4}$$

and it is small at high energies.

A simple model is considered for the amplitude of the $\gamma^\star \to J/\Psi$ transition. The virtual photon is going to the $q\bar{q}$ state and the $q\bar{q} \to V$ amplitude is described by a non-relativistic wave function [3, 12]. In this approximation, quarks have the same momenta k equal to half of the vector meson momentum and mass $m_c = m_J/2$. Gluons from the Pomeron are coupled with the single and different quarks in the $c\bar{c}$ loop. This ensures the gauge invariance of the final result.

The spin-average and spin dependent cross sections of the J/Ψ leptoproduction with parallel and antiparallel longitudinal polarization of a lepton and a proton are determined by the relation

$$d\sigma(\pm) = \frac{1}{2}\left(d\sigma(\overset{\rightarrow}{\leftarrow}) \pm d\sigma(\overset{\rightarrow}{\rightarrow})\right). \tag{5}$$

The cross section $d\sigma(\pm)$ can be written in the form

$$\frac{d\sigma^\pm}{dQ^2 dy dt} = \frac{|T^\pm|^2}{32(2\pi)^3 Q^2 s^2 y}. \tag{6}$$

For the spin-average amplitude square we find [14]

$$|T^+|^2 = s^2 N \left((2 - 2y + y^2)m_J^2 + 2(1 - y)Q^2\right)\left[|\tilde{B} + 2m\tilde{A}|^2 + |\tilde{A}|^2|t|\right]. \tag{7}$$

Here the term proportional to $(2 - 2y + y^2)m_J^2$ represents the contribution of the virtual photon with transverse polarization. The $2(1 - y)Q^2$ term describes the effect of longitudinal photons. The N factor in (7) is normalization, and the $\tilde{A}$ and $\tilde{B}$ functions are expressed through the integral over transverse momentum of the gluon. The function $\tilde{B}$ is determined by

$$
\begin{aligned}
\tilde{B} &= \frac{1}{4\bar{Q}^2} \int \frac{d^2 l_\perp (l_\perp^2 + \vec{l}_\perp \vec{\Delta}) B(l_\perp^2, x_P, ...)}{(l_\perp^2 + \lambda^2)((\vec{l}_\perp + \vec{\Delta})^2 + \lambda^2)[l_\perp^2 + \vec{l}_\perp \vec{\Delta} + \bar{Q}^2]} \\
&\sim \frac{1}{4\bar{Q}^4} \int_0^{l_\perp^2 < \bar{Q}^2} \frac{d^2 l_\perp (l_\perp^2 + \vec{l}_\perp \vec{\Delta})}{(l_\perp^2 + \lambda^2)((\vec{l}_\perp + \vec{\Delta})^2 + \lambda^2)} B(l_\perp^2, x_P, ...).
\end{aligned}
\tag{8}
$$

with $\bar{Q}^2 = (m_J^2 + Q^2 + |t|)/4$. The term $(l_\perp^2 + \vec{l}_\perp \vec{\Delta})$ appears in the numerator of (8) because of the cancellation between the graphs where gluons are coupled with the single and different quarks. The $\tilde{A}$ function is determined by the similar integral.

The integral (8) is found to be connected with the gluon SPD

$$\mathcal{F}_{x_P}^g(x_P,t) = \int_0^{l_\perp^2 < \bar{Q}^2} \frac{d^2 l_\perp (l_\perp^2 + \vec{l}_\perp \vec{\Delta})}{(l_\perp^2 + \lambda^2)((\vec{l}_\perp + \vec{\Delta})^2 + \lambda^2)} B(l_\perp^2, x_P, ...). \tag{9}$$

We find that $B(l_\perp^2, x_P, ...)$ is the unintegrated spin- average gluon distribution. The $\tilde{A}$ function can be determined in terms of the $\mathcal{K}_{x_P}^g(x_P,t)$ distribution. Determination of the gluon distribution functions can be found in [13], e.g.

The spin-dependent amplitude square looks like

$$|T^-|^2 = s|t|(2-y)N \left[|\tilde{B}|^2 + m(\tilde{A}^\star \tilde{B} + \tilde{A}\tilde{B}^\star) \right] m_J^2. \tag{10}$$
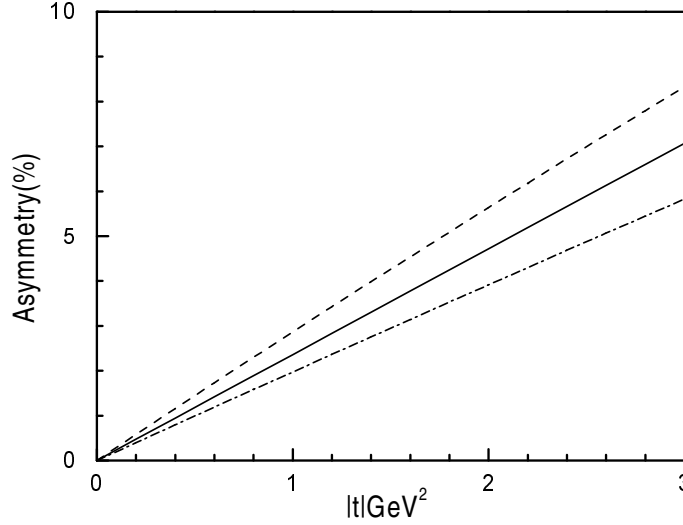

Fig. 1. The A_{ll} asymmetry of the J/Ψ production at HERMES: solid line -for $\alpha_{flip} = 0$; dot-dashed line -for $\alpha_{flip} = -0.1$; dashed line -for $\alpha_{flip} = 0.1$

The A_{ll} asymmetry for not high Q^2 is determined by

$$A_{ll} = \frac{\sigma(-)}{\sigma(+)} \sim \frac{|t|}{s} \frac{(2-y)\left[|\tilde{B}(t)|^2 + m(\tilde{A}(t)^\star \tilde{B}(t) + \tilde{A}(t)\tilde{B}(t)^\star)\right]}{(2-2y+y^2)\left[|\tilde{B}(t) + 2m\tilde{A}(t)|^2 + |t||\tilde{A}(t)|^2\right]}. \tag{11}$$

It has been shown in [16] that the A_{ll} asymmetry in the diffractive processes is proportional to x_P. For the diffractive vector meson production $x_P \sim 1/s$ see (4). As a result, the obtained A_{ll} asymmetry decreases with growing energy.

The A_{ll} asymmetry also depends on the ratio of the spin-flip to the non-flip parts of the coupling (1) $\alpha_{flip} = \tilde{A}(t)/\tilde{B}(t)$ which has been found in (2) to be about 0.1. The predicted asymmetry at HERMES energies is shown in Fig. 1. The contribution of the spin-dependent A term in (1) to the double spin A_{ll} asymmetry of the J/Ψ production does not exceed two per cent for the momentum transfer $|t| \leq 1\text{GeV}^2$. Sensitivity of the asymmetry to α is rather weak. At HERA energies, the asymmetry will be negligible.

3 Spin effects in $Q\bar{Q}$ production

Now we are interested in the diffractive $Q\bar{Q}$ leptoproduction. This reaction might be determined in terms of variables (3). However, the mass of the produced hadron system is not fixed here and an additional variable $\beta = x/x_P$ appears. In the two-gluon picture of the Pomeron we consider the graphs of Fig. 2. The cross
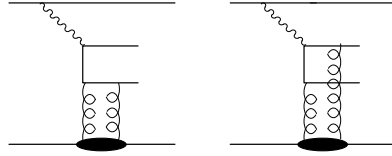

Fig. 2. Two-gluon contribution to $Q\bar{Q}$ production

section is determined by the square of the graphs shown in Fig. 2, and includes, together with the planar, the nonplanar contribution with the crossed quark lines. The spin-average and spin-dependent cross section can be written in the form

$$\frac{d^5\sigma(\pm)}{dQ^2 dy dx_P dt dk_\perp^2} = \binom{(2-2y+y^2)}{(2-y)} \frac{C(x_P,Q^2)\, N(\pm)}{\sqrt{1 - 4k_\perp^2 \beta/Q^2}}. \tag{12}$$

Here $C(x_P,Q^2)$ is a normalization function which is common for the spin average and spin dependent cross section. The planar contribution to N^+ (sum of diagrams with non-crossed quark lines) looks like

$$N_P^+ = (m_c^2 + (\vec{k}_\perp + \vec{r}_\perp)^2)\left(|\tilde{B} + 2m\tilde{A}|^2 + |\tilde{A}|^2|t|\right) \tag{13}$$

with

$$
\begin{aligned}
\tilde{B} &= \frac{1}{\bar{Q}_1^2} \int \frac{d^2l_\perp (l_\perp^2 + \vec{l}_\perp \vec{\Delta} - \vec{l}_\perp \vec{k}_\perp) B(l_\perp^2, x_P, ...)}{(l_\perp^2 + \lambda^2)((\vec{l}_\perp + \vec{\Delta})^2 + \lambda^2)[(\vec{l}_\perp - \vec{k}_\perp)^2 + m_c^2]} \\
&\sim \frac{1}{\bar{Q}_1^4} \int_0^{l_\perp^2 < \bar{Q}_1^2} \frac{d^2l_\perp (l_\perp^2 + \vec{l}_\perp \vec{\Delta})}{(l_\perp^2 + \lambda^2)((\vec{l}_\perp + \vec{\Delta})^2 + \lambda^2)} B(l_\perp^2, x_P, ...) \\
&= \frac{1}{\bar{Q}_1^4} \mathcal{F}_{x_P}^g(x_P, t, \bar{Q}_1^2) \tag{14}
\end{aligned}
$$

where $Q_1^2 = m_c^2 + \vec{k}_\perp^2$ and k is a quark momentum.

The calculation shows considerable cancellation between the contributions where gluons are coupled with the single and different quarks (Fig. 2). As a result, the numerator of the integral for the function $\tilde{B}$ (14) is vanishing when the gluon momentum $l_\perp$ is going to zero as in the vector meson production. Corresponding integrals for $\tilde{A}$ have a similar form. We see that the cross section of the diffractive $Q\bar{Q}$ production is expressed through the same skewed gluon distributions as the vector meson production but at a different scale.
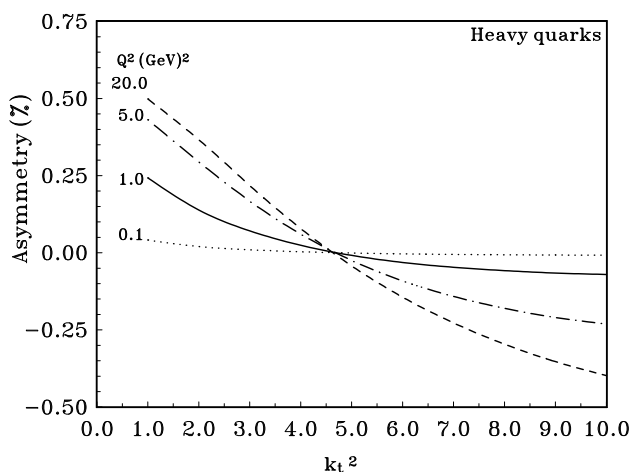

Fig. 3. The predicted Q^2 dependence of the A_{ll} asymmetry for the $c\bar{c}$ production at COMPASS for $\alpha = 0.1 \text{GeV}^{-1}$, x_P=0.1, y=0.5

Similar calculations have been made for the spin-dependent part of the cross section $\sigma(-)$. We shall discuss here the $A_{ll} = \sigma(-)/\sigma(+)$ asymmetry at COMPASS [15]. The obtained asymmetry is proportional to x_P (here x_P is typically of about $.05 - .1$) and has a weak energy dependence, Fig. 3. The predicted asymmetry is quite small and does not exceed 1%. It has a week dependence on the $\alpha = \tilde{A}/\tilde{B}$ ratio. The Q^2 dependence of the A_{ll} asymmetry of the diffractive open charm production can be estimated as $A_{ll} \propto Q^2/(Q^2 + Q_0^2)$ with $Q_0^2 \sim 1 \text{GeV}^2$.

We know from the study of elastic scattering that the A structure in (1) is mainly responsible for the transverse asymmetry. Not small single-spin asymmetry in $Q\bar{Q}$ production caused by the A term has been predicted in [17]. This term should contribute to the A_{lT} asymmetry with longitudinal lepton and transverse proton polarization. The calculation of this asymmetry is similar to the analysis of A_{ll} which was made before. It has been found that the A_{lT} asymmetry is not small and proportional to the $\alpha = \tilde{A}/\tilde{B}$ ratio. Also the A_{lT} asymmetry is proportional
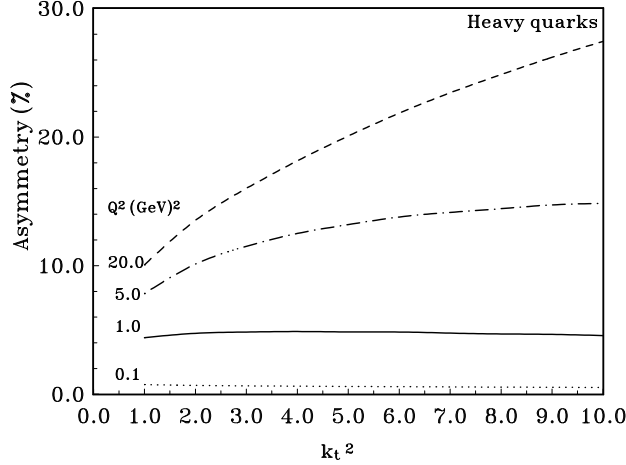
Fig. 4. The predicted Q^2 dependence of the A_{lT} asymmetry for the $c\bar{c}$ production at COMPASS for $\alpha = 0.1\text{GeV}^{-1}$, x_P=0.1, y=0.5

to the scalar production of the proton spin vector and the jet momentum $A_{lT} \propto$ $(s_\perp \cdot k_\perp) \propto \cos(\phi_{Jet})$. Thus, the asymmetry integrated over the azimuthal jet angle ϕ_{Jet} is zero. We have calculated the A_{lT} asymmetry for the case when the proton spin vector is perpendicular to the lepton scattering plane and the jet momentum is parallel to this spin vector. The predicted asymmetry is show in Fig. 4. It is huge and has a drastic $k_\perp^2$ dependence. The large value of the A_{lT} asymmetry is caused by the fact that in contrast to A_{ll}, it is not proportional to small x_P.

4   Conclusion

In this report the double spin asymmetries in the diffractive hadron leptoproduction have been investigated using the two-gluon picture of the Pomeron. We have considered all the graphs where the gluons from the Pomeron couple to a different quark in the loop and to the single one. This provides a gauge-invariant scattering amplitude. Our calculations show that the spin–dependent structure A in (1) does not provide a considerable contribution to the A_{ll} asymmetry. The predicted A_{ll} asymmetry is smaller than 1-2%. Not small effects in the double spin A_{ll} asymmetry should be determined by the $\Delta G \propto D\gamma_\rho\gamma_5$ term of the vertex (1). This contribution was not investigated here but can be important for Compass experiment at small $x \leq 0.1$. However, the results obtained here show that the diffractive asymmetry in the $Q\bar{Q}$ production vanishes as $Q^2 \to 0$. We hope that this conclusion is true for the ΔG term, too. If so, such effects, most likely, do not

provide additional troubles in extracting ΔG from the A_{ll} asymmetry. The reason is that the COMPASS experiment is planing to study events of the charm quark production at small Q^2 where the diffractive asymmetry is expected be extremely small.

It is shown here that the A_{lT} asymmetry of the diffractive heavy quark production is determined by the A structure in (1). This asymmetry is predicted to be not small, about 10-20%. It can give direct information about the spin-dependent structure A in the ggp coupling. Note that it is usually difficult to detect an outgoing proton in fixed target experiments. Then, the cross section integrated over the momentum transfer t are measured. Our analyses show that such an integrated asymmetry is smaller by a factor of 1.5–2 than the unintegrated values shown in Figs 3, 4.

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References

[1] F.E. Low: Phys. Rev. D **12** (1975) 163;
     S. Nussinov: Phys. Rev. Lett. **34** (1975) 1286.

[2] A.V. Radyushkin: Phys.Rev, D **56** (1997) 5524;
      X. Ji, Phys.Rev: D **55** (1997) 7114.

[3] M.G.Ryskin, Z.Phys C **57** (1993) 89.

[4] S.J. Brodsky at al: Phys. Rev. D **50**, (1994) 3134.

[5] M. Anselmino, P. Kroll, B. Pire: Z.Phys. C **36**, (1987) 36.

[6] S.V. Goloskokov, P. Kroll: Phys. Rev. D **60** (1999) 014019.

[7] T. Arens, M. Diehl, O. Nachtmann, P.V. Landshoff: Z. Phys. C **74** (1997) 651.

[8] S.V. Goloskokov, S.P. Kuleshov, O.V. Selyugin: Z. Phys. C **50** (1991) 455.

[9] N. Akchurin, S. V. Goloskokov, O. V. Selyugin: Int. J. Mod. Phys. A **14** (1999) 253.

[10] D. C. Peaslee et al.: Phys. Rev. Lett. **51** (1983) 2358 ;
     G. Fidecaro at al.: Phys. Lett. B **105** (1981) 309.

[11] J. Bartels, T. Gehrmann, M.G.Ryskin: Eur.Phys.J. C **11** (1999) 325.

[12] M. Diehl, Eur.Phys.J. C **4** (1998) 497.

[13] M. Diehl, T. Feldmann, R. Jakob, P. Kroll, Eur.Phys.J. C **8** (1999) 409.

[14] S.V. Goloskokov: Eur. Phys. J. C **11** (1999) 309.

[15] COMPASS Collaboration, G. Baum et al: Proposal COMPASS, CERN/SPSLC 96-16, (1996).

[16] S.V. Goloskokov: Mod. Phys. Lett. A **12** (1997) 173.

[17] S.V. Goloskokov: Phys.Rev. D **53** (1996) 5995.